

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:
Nguyen, et al

Art Unit: 1771

Serial No. 10/005,846

Examiner: Victor S. Chang

Filed: December 3, 2001

For: DIFFUSION MEMBRANE

REPLY BRIEF

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Commissioner for Patents
P. O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

This Reply to Examiner's Answer, is filed in response to the Examiner's Answer mailed November 3, 2006. It relates to the Order Remanding to the Examiner decided September 8, 2006.

CERTIFICATE OF EFS TRANSMISSION

I hereby certify that this correspondence is being filed electronically with the United States Patent and Trademark Office on December 6, 2006.



Scott E. Hanf

Table of Contents

	<u>Section</u>	<u>Page #</u>
1. Identification Page		1
2. Table of Contents		2
3. Real Party in Interest	I	3
4. Related appeals & Interferences	II	3
5. Status of Claims	III	3-4
6. Status of Amendment	IV	3
7. Summary of Claimed Subject Matter	V	4-6
8. Grounds of rejections to be reviewed on Appeal	VI	6
9. Argument	VII	6-22
10. Claims Appendix	VIII	23-25
11. Evidence Appendix	IX	26-57
a. Japanese Translation	27-45	
b. Text Book	46-57	
12. Related Proceedings Appendix	X	58-59

I. REAL PARTY IN INTEREST

The real party in interest is Celgard Inc., the assignee of record in the instant application.

II. RELATED APPEALS AND INTERFERENCES

There are no related interferences. Applicants filed a previous appeal in this matter on February 24, 2004, which resulted in reopening of prosecution in an Official Action of April 24, 2004. Applicants again filed an appeal on June 10, 2005, this case was sent to the board which ruled on September 8, 2006, that the rejects under 35 USC §102(a) ". . . can be found only when the reference discloses exactly what is claimed and that where there are differences between the reference disclosed and the claim, the rejection must be based on § 103 which takes differences into account". Despite this admonishment of the board the examiner has chosen to maintain the rejection under 35 USC § 102(b), which has only increased the cost to applicant, to respond to these frivolous rejections, and waste the time and energy of the board. Applicant maintains the appeal as the examiner has only begrudgingly asserted an alternative rejection under 35 USC § 103(a).

III. STATUS OF THE CLAIMS

Claims 1-3 and 6-11 stood rejected under 35 U.S.C. § 102(b), as being anticipated by JP 10-017694. After the board's remand to

the examiner, of September 8, 2006, in an Examiner's Answer now claims 1-11 also stand rejected under 35 U.S.C. § 102(b), as being anticipated by JP 10-017694 and in the alternative, stand rejected under 35 U.S.C. § 103(a), as being obvious from JP 10-017694. Claims 1-11 are the subject of this Appeal.

IV. STATUS OF AMENDMENTS

No Claim was amended after the Final Rejection and prior to this Appeal.

V. SUMMARY OF THE CLAIMED SUBJECT MATTER

The following is a concise explanation of the subject matter defined in independent claims 1, 8 and 9.

According to Claim 1, the instant invention is a method of improving the mechanical strength of a membrane (specification page 2, last sentence). This method is comprised of the step of providing a microporous sheet (specification, page 5, first paragraph) comprising a blend of an aliphatic polyolefin and a thermoplastic olefin elastomer selected from the group of ethylene-propylene rubbers, ethylene-propylene-diene terpolymer rubbers, and combinations thereof (specification, page 5, paragraphs 1, 2 and 3, with paragraph 3 extending to page 6.) with the elastomer

comprising less than 10 percent by blend weight (specification, page 5, paragraph 1).

According to Claim 8, the instant invention is a method of improving the mechanical strength of a membrane (specification page 2, last sentence). This method is comprised of the step of providing a microporous sheet (specification, page 5, first paragraph) having a Gurley air permeability less than 35 seconds/10cc (specification, page 4, second paragraph) comprising a blend of an aliphatic polyolefin selected from the group consisting of polyethylene, polypropylene, copolymers thereof, and blends thereof, and a thermoplastic olefin elastomer being selected from the group consisting of ethylene-propylene rubbers, ethylene-propylene-diene terpolymer rubbers, and combinations thereof (specification, page 5, paragraphs 1, 2 and 3, with paragraph 3 extending to page 6), with the elastomer comprising 3 to 7 percent by blend weight (specification, page 5, paragraph 1).

According to Claim 8, the instant invention is a diffusion membrane (specification, page 3, paragraph 3). This diffusion membrane is comprised of a dry stretched microporous sheet (specification, page 7, paragraph 1) comprising a blend of an aliphatic polyolefin and a thermoplastic olefin elastomer (specification, page 5, paragraph 1), the elastomer comprising

less than 10 percent by blend weight (specification, page 5, paragraph 1), the polyolefin being selected from the group consisting of polyethylene, polypropylene, copolymers thereof, and blends thereof, the thermoplastic olefin elastomer being selected from the group consisting of ethylene-propylene rubbers, ethylene-propylene-diene terpolymer rubbers, and combinations thereof (specification, page 5, paragraphs 1, 2 and 3, with paragraph 3 extending to page 6).

VI. GROUND'S OF REJECTION TO BE REVIEWED ON APPEAL

Claims 1-11 stand rejected under 35 U.S.C. § 102(b), as being anticipated by JP 10-017694 and in the alternative, stand rejected under 35 U.S.C. § 103(a), as being obvious from JP 10-017694.

VII. ARGUMENT

§ 102

The Section 102 rejection based on JP 10-017694 (computer translation) is improper and must be removed. The Examiner has rejection of claims 1-11 as being anticipated by JP 10-017694 (computer translation) under Section 102.

To anticipate a claim, a single source must contain all of the elements of the claim. *See Hybritech Inc. v. Monoclonal Antibodies, Inc.*, 802 F.2d 1367, 1379, 231 USPQ 81, 90 (Fed. Cir.

1986); *Atlas Powder Co. v. E.I. du Pont De Nemours & Co.*, 750 F.2d 1569, 1574, 224 USPQ 409, 411 (Fed. Cir. 1984); *In re Marshall*, 578 F.2d 301, 304, 198 USPQ 344, 346 (C.C.P.A. 1978). Missing elements may not be supplied by the knowledge of one skilled in the art or the disclosure of another reference. See *Structural Rubber Prods. Co. v. Park Rubber Co.*, 749 F.2d 707, 716, 223 USPQ 1264, 1271 (Fed. Cir. 1984). Where a reference discloses less than all of the claimed elements, an Examiner may only rely on 35 USC § 103. See *Titanium Metals Corp. v. Banner*, 778 F.2d 775, 780, 227 USPQ 773, 777 (Fed. Cir. 1985).

JP 10-017694 (computer translation) fails to teach or suggest a process that increases the mechanical strength of a membrane by adding an elastomer comprising less than 10 percent by blend weight. The Examiner now claims that the benefit must be inherent in JP'694 (Examiners Answer page 4). The case law is clear, where a reference discloses less than all of the claimed elements, an Examiner may only rely on 35 USC § 103. However there is no rejection to claim 1-3 and 6-11 under 35 USC § 103 the only under 35 USC § 102(b). It should be clear that in a process claim that teaches increasing the mechanical strength of a membrane by adding an elastomer that in order to anticipate the claim the reference needs to teach this point. JP'694 fails to do this. The increased

mechanical strength of the instant invention is clearly illustrated in the specification as filed, on page 8 in table 1.

Nowhere in JP 10-017694 is it taught, or suggests, a process that increases the mechanical strength of a membrane by adding an elastomer comprising less than 10 percent by blend weight. That is only done by the present invention. Yet this is clearly the requirement of a rejection under 35 USC § 102(b).

Claims 1-11 must be allowed under 35 USC § 102(b) as the case law is clear, where a reference discloses less than all of the claimed elements, an Examiner may only rely on 35 USC § 103.

With respect to claims 1-7, the Examiner is once again reminded that, new uses for compositions of matter are clearly allowable under the 35 USC, as can be demonstrated by the definition of the term process under 35 USC § 100(b) which reads:

(b) The term "process" means process, art or method, and includes a new use of a known process, machine, manufacture, composition of matter, or material.

The current claims pending under this Official Action are drawn as method claims to a new use of a known composition of matter or material. Therefore they are essentially a new use for a known material which are clearly allowable under 35 USC § 100(b).

In the Instant Invention the microporous sheet comprising a blend of an aliphatic polyolefin and a thermoplastic olefin elastomer is a known composition of matter or material, however "the method of improving the mechanical strength of a membrane comprising the step of: providing" constitutes a new use. The Claim is written in proper method or process format in accordance with 35 USC § 100(b).

With respect to independent claim 8 the Examiner admits on page 4 of the Examiner's Answer that JP '694 is silent about the Gurley Value of its microporous membrane, yet it is clearly an element of the claim and there should be no question that to anticipate a claim, a single source must contain all of the elements of the claim. Here the Examiner clearly admits that the element is missing, the claim is rejected under 35 USC § 102(b) therefore claim 8 must be patentable over JP '694.

With respect to independent claim 9 this claim was amended in the Amendment filed on November 22, 2005, basis for this amendment can be found on page 4 of the specification as filed. The claim is written so that one of ordinary skill in the art knows that the microporous sheet was made by the dry stretch process. It should be clear from the translation Applicants' filed with the appeal

that JP '694 teaches the production of a microporous membrane only through extraction or the wet process which produces a microporous membrane with a completely different physical structure. JP '694 in paragraph 0019 clear teaches that: the microporous membranes of this reference are produced by a plasticizer being extracted from the membrane. In Applicants' appeal brief a copy of Synthetic Polymer Membrane a Structural Perspective, by Robert E. Kesting, Second Edition, Copyright 1985 where the dry stretched process is described and pictures of the porous it forms are shown on pages 290-297 and the solvent extraction process and the porous it forms are clearly shown on pages 251-261.

The Examiner in his answer of July 20, 2005, argues that phrase dry stretch is never defined. This is not true. On page 4 of the specification Applicants teach that these membranes can be made by a dry stretch method and reference to the Kesting reference at pages 237-297. On page 290 this reference describes the Celgard® or dry stretch process:

In many respects the Celgard® process, in which semicrystalline films or fibers are extruded from the melt and porosity induced by simply stretching the finished articles in the solid state, represents the ideal insofar as the manufacturing of microporous membranes is concerned. No solvents are required.

Dry stretched material has porosity induced by stretching in the solid state, no solvent, no plasticizer. If Applicant would have said by the Celgard® process the Examiner would simply have objected to using a Trademark in the claim making it indefinite.

In JP'694 teaches in paragraph 0016 that a plasticizer is added, in paragraph 0017 that the polymer gel is formed into a sheet, in paragraph 0018 the sheet is stretched, and in paragraph 0019 that the plasticizer is extracted to form the microporous membrane. This is not dry stretch process; it requires a plasticizer to be extracted to create the microporous. This difference would be obvious to one of ordinary skill.

As JP'694 clear fails to teach dry stretch method for the formation of the micropores, claims 9-11 must be allowable over JP'694 under 35 USC 35 USC § 102(b).

Applicant notes that the Board in their remand of September 8, 2006, quoted the case of *Atofina v. Great Lakes Chemical Corp.*, 441 F.3d 991, 999, 78 USPQ2d 1417, 1423 (Fed. Cir. 2006); *Perricone v. Medicis Pharmaceutical Corp.*, 432 F.3d 1368, 1372, 77 USPQ 2d 1321, 1326 (Fed. Cir. 2005); *Titanium Metals Corp. of Am. v. Banner*, 778 F.2d 775, 780, 227 USPQ 773, 777 (Fed. Cir. 1985) ("[A]nticipation under §102 can be found only when the reference discloses exactly

what is claimed and that where there are differences between the reference disclosed and the claim, the rejection must be based on § 103 which takes differences into account. D Chisum on Patents § 3.02."); *In re Malagari*, 499 F.2d 1297, 1303, 182 USPQ 549, 552 (CCPA 1974); and *In re Reven*, 390 F.2d 997, 1001, 156 USPQ 679, 681 (CCPA 1968).

§ 103

The Examiner after the remand from the Board now also rejects claims 1-11 under 35 USC §103(a) as being obvious from JP 10-017694. Here the Examiner clearly admits that an element is missing from the claims (that there is no specific reference to the feature of providing an olefin elastomer that comprises less than 10% by blend weight). In order for a claim to be anticipated under 35 USC § 103 the office must make out a *prima facie* case of obviousness. The prior art reference or combination of references must teach or suggest all the limitations of the claims. See *In re Zurko*, 111 F.3d 887, 888-89, 42 U.S.P.Q.2d 1476, 1478 (Fed. Cir. 1997); *In re Wilson*, 424 F.2d 1382, 1385, 165 U.S.P.Q. 494, 496 (C.C.P.A. 1970) ("All words in a claim must be considered in judging the patentability of that claim against the prior art."). And the teachings or suggestions, as well as the expectation of success, must come from the prior art, not Applicants' disclosure.

See *In re Vaeck*, 947 F.2d 488, 493, 20 U.S.P.Q.2d 1438, 1442 (Fed. Cir. 1991).

Here is the crux of the appeal. Claims 1-8 that are now up on appeal are process claims which address the problem of increasing mechanical strength of a membrane. On page 3 of the Examiner's Answer the examiner in the last paragraph avers that he can ignore these limitations. Applicants disagree.

With respect to claims 1-8, the examiner is once again reminded that, new uses for compositions of matter are clearly allowable under the 35 USC, as can be demonstrated by the definition of the term process under 35 USC § 100(b) which reads:

(b) The term "process" means process, art or method, and includes a new use of a known process, machine, manufacture, composition of matter, or material.

The current claims pending under this Official Action are drawn as method claims to a new use of a known composition of matter or material. Therefore they are essentially a new use for a known material which are clearly allowable under 35 USC § 100(b).

In the Instant Invention the microporous sheet comprising a blend of an aliphatic polyolefin and a thermoplastic olefin elastomer is a known composition of matter or material, however

"the method of improving the mechanical strength of a membrane comprising the step of: providing" constitutes a new use. The claims are written in proper method or process format in accordance with 35 USC § 100(b).

Now if one actually reads the cited reference JP 10-017694 it becomes clear that there is no teaching or suggestion that by adding an olefin elastomer that comprises less than 10% by blend weight that the mechanical strength of the separator can be improved.

If one looks at the Cited reference JP 10-017694 it is clear that none of the examples in this reference add any olefin elastomer to their compositions. Yet the case law is clear, the prior art reference or combination of references must teach or suggest all the limitations of the claims. See *In re Zurko*, 111 F.3d 887, 888-89, 42 U.S.P.Q.2d 1476, 1478 (Fed. Cir. 1997); *In re Wilson*, 424 F.2d 1382, 1385, 165 U.S.P.Q. 494, 496 (C.C.P.A. 1970) ("All words in a claim must be considered in judging the patentability of that claim against the prior art."). And the teachings or suggestions, as well as the expectation of success, must come from the prior art, not Applicants' disclosure.

With respect to claims 1-8 the examiner admits that he deals with the feature of increasing mechanical strength by ignoring the limitation because the process claim has a single step, yet cites no case law in support of this conclusion.

The examiner avers that the reference JP10-017694 teaches that blends of polyethylene with less than 30% of EPR by weight can be used to make a membrane and under 35 USC §103 getting to the feature of using less than 10% by weight is obvious optimization, motivated by the desire to obtain required amount of beneficial effect using a blend. But what does this mean? What is the desired beneficial effect? If one actually reads JP10-017694 see paragraph [0013] of the translation attached to the evidence appendix (pages 33 & 34), this reference says that a high density polyethylene should be used, however one can still make a membrane having acceptable performance by using a blend with "no more than 30% polyolefin, such as polypropylene, medium density polyethylene, linear low density polyethylene, low density polyethylene, and EPR may also be used." This just says use the good stuff, high density polyethylene, but if you must throw in something to bring down the price make sure not to use any more 30% of the cheaper material. This reference neither teaches, nor suggests that any benefit can be had by the addition of the polyolefin to the high density polyethylene.

Where the prior art has not recognized the "result-effective" capability of a particular invention parameter, no expectation would exist that optimizing the parameter would successfully yield the desired improvement. *In re Antonie*, 559 F.2d 618, 195 U.S.P.Q. 6 (C.C.P.A. 1977).

Antonie claimed an apparatus for treating waste water. The apparatus included a tank having continuously rotating semi-immersed contactors (discs). *Antonie* discovered that a ratio of tank volume to contactor area of 0.12 gals./sq. ft. maximized the treatment capacity of the equipment.

The PTO cited a single reference disclosing the same basic structure, but lacking any disclosure of a tank volume to contactor ratio of 0.12. Indeed, the reference did not suggest any reason to calculate the tank volume to contactor area ratio, much less to select a specific magnitude. The PTO still considered an apparatus having the claimed ratio an obvious modification of the prior art apparatus. In the PTO's view, optimizing efficiency by varying parameter magnitude represented a mere matter of mechanical experimentation.

In reviewing the board's decision, the CCPA stated that an evaluation of the obviousness of the invention as a whole requires looking "not only to the subject matter which is literally recited in the claim in question (the ratio value) but also to those properties of the subject matter which are inherent in the subject matter and are disclosed in the specification." *Id.* at 619, 195 U.S.P.Q. at 8 (citation omitted). "In this case, the invention as a whole is the ratio value of 0.12 and its inherent and disclosed property." *Id.*

The unsuggested recognition by *Antonie* of the relationship between the result produced and the particular design parameters was the touchstone of unobviousness here. Acknowledging that it would ordinarily consider mere optimization of a variable in a known process *prima facie* obvious, the court noted two exceptions to this rule: In cases where optimizing a known result-effective variable produced unexpectedly good results and in the present case, where the art did not recognize that the parameter optimized was a result-effective variable. *Id.* at 620, 195 U.S.P.Q. at 8-9.

The examiner argues that optimization of the ratio of EPR gives him *prima facie* obviousness, this is not the case. As in *Antonie* the instant invention falls under the exception to the

rule, where the art did not recognize that the parameter optimized was a result-effective variable. *Id.* at 620, 195 U.S.P.Q. at 8-9. Therefore precedence dictates that the Board must overturn the examiner's baseless rejections of claims 1-8, and allow the claims.

Applicants respectfully request that the Board allows claim 1-8 as the examiner has clearly failed to make a legitimate *prima facie* case as required under 35 USC §103.

With respect to claims 9-11, Claim 9 is the independent claim which teaches that the diffusion membrane is a dry stretch membrane. With respect to independent claim 9 this claim was amended in the Amendment filed on November 22, 2005, basis for this amendment can be found on page 4 of the specification as filed. The claim is written so that one of ordinary skill in the art knows that the microporous sheet was made by the dry stretch process. It should be clear from the translation Applicants' filed with the appeal that JP '694 teaches the production of a microporous membrane only through extraction or the wet process which produces a microporous membrane with a completely different physical structure. JP '694 in paragraph 0019 clearly teaches that: the microporous membranes of this reference are produced by a plasticizer being extracted from the membrane. In Applicants' appeal brief of June 10, 2005, a copy of Synthetic Polymer Membrane

a Structural Perspective, by Robert E. Kesting, Second Edition, Copyright 1985 where the dry stretched process is described and pictures of the porous it forms are shown on pages 290-297 and the solvent extraction process and the porous it forms are clearly shown on pages 251-261.

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Dry stretched material has porosity induced by stretching in the solid state, no solvent, no plasticizer. If Applicant would have said by the Celgard® process the Examiner would simply have objected to using a Trademark in the claim making it indefinite.

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sheet, in paragraph 0018 the sheet is stretched, and in paragraph 0019 that the plasticizer is extracted to form the microporous membrane. This is not a dry stretch process; it requires a plasticizer to be extracted to create the microporous. This difference would be obvious to one of ordinary skill.

If one looks at the Cited reference JP 10-017694 it is clear that this reference fails to teach or suggest any membrane made by the dry stretch or Celgard® process. Yet the case law is clear, the prior art reference or combination of references must teach or suggest all the limitations of the claims. See *In re Zurko*, 111 F.3d 887, 888-89, 42 U.S.P.Q.2d 1476, 1478 (Fed. Cir. 1997); *In re Wilson*, 424 F.2d 1382, 1385, 165 U.S.P.Q. 494, 496 (C.C.P.A. 1970) ("All words in a claim must be considered in judging the patentability of that claim against the prior art."). And the teachings or suggestions, as well as the expectation of success, must come from the prior art, not Applicants' disclosure.

Applicants respectfully request that the Board allows claim 9-11 as the examiner has clearly failed to make a legitimate *prima facie* case as required under 35 USC §103.

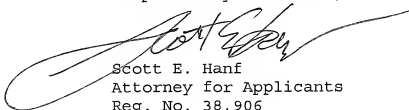
Finally in the remand the Board cited the case *Atofina v. Great Lakes Chemical Corp.*, 441 F.3d 991, 999, 78 USPQ2d 1417, 1423

(Fed. Cir. 2006); *Perricone v. Medicis Pharmaceutical Corp.*, 432 F.3d 1368, 1372, 77 USPQ 2d 1321, 1326 (Fed. Cir. 2005) where the Plaintiff's patent was ultimately view as invalid, for inequitable conduct. Specifically, the inequitable conduct was found for not disclosing a translation of a cited Japanese translation. This case can be distinguished from this cited case. Applicants only became aware of cited reference JP10-017694. After the examiner cited the reference in the Official action of September 29, 2004, Applicants in response to this official action had the reference translated and sent in a copy of the translated reference to the examiner on November 22, 2004. The translation of the reference JP10-017694 should have been entered it into the record on November 22, 2004.

Conclusion

In view of the foregoing, Appellants respectfully request that the rejection be overturned and that the instant application be allowed to proceed to issuance. Applicants respectfully request that the Examiner either allow this case or send this appeal to the board.

Respectfully submitted,

A handwritten signature in black ink, appearing to read "Scott E. Hanf", written over a horizontal line.

Scott E. Hanf
Attorney for Applicants
Reg. No. 38,906

Customer No. 29494
HAMMER & HANF, P.C.
3125 Springbank Lane
Suite G
Charlotte, NC 28226
Telephone: 704-927-0400
Facsimile: 704-927-0485

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VIII. CLAIM APPENDIX

1. (Previously presented) A method of improving the mechanical strength of a membrane comprising the step of:
providing a microporous sheet comprising a blend of an aliphatic polyolefin and a thermoplastic olefin elastomer selected from the group of ethylene-propylene rubbers, ethylene-propylene-diene terpolymer rubbers, and combinations thereof with the elastomer comprising less than 10 percent by blend weight.
2. (original) The method of Claim 1 wherein the elastomer comprises about 2 to 10 percent by blend weight.
3. (original) The method of Claim 2 wherein the elastomer comprises about 3 to 7 percent by blend weight.
4. (Previously presented) The method of Claim 1 wherein the microporous sheet has a Gurley air permeability less than 35 seconds/10cc.

5. (Previously presented) The method of Claim 4 wherein the microporous sheet has a Gurley air permeability less than 25 seconds/10cc.

6. (original) The method of Claim 1 wherein the polyolefins selected from polyethylene, polypropylene, copolymers thereof, and blends thereof.

7. (original) The method of Claim 1 wherein the thermoplastic olefin elastomer is selected from the group of ethylene-propylene rubbers, ethylene-propylene-diene terpolymer rubber, and combinations thereof.

8. (Previously presented) A method of improving the mechanical strength of a membrane comprising the step of:

providing a microporous sheet having a Gurley air permeability less than 35 seconds/10cc comprising a blend of an aliphatic polyolefin selected from the group consisting of polyethylene, polypropylene, copolymers thereof, and blends thereof, and a thermoplastic olefin elastomer being selected from the group consisting of ethylene-propylene rubbers, ethylene-propylene-diene terpolymer rubbers, and combinations thereof, with the elastomer comprising 3 to 7 percent by blend weight.

9. (Previously presented) A diffusion membrane comprising:

a dry stretched microporous sheet comprising a blend of an aliphatic polyolefin and a thermoplastic olefin elastomer, the elastomer comprising less than 10 percent by blend weight, the polyolefin being selected from the group consisting of polyethylene, polypropylene, copolymers thereof, and blends thereof, the thermoplastic olefin elastomer being selected from the group consisting of ethylene-propylene rubbers, ethylene-propylene-diene terpolymer rubbers, and combinations thereof.

10. (Previously presented) The membrane of Claim 9 wherein the elastomer comprises between 2 and 10 percent by blend weight.

11. (Previously presented) The membrane of Claim 10 wherein the elastomer comprises between 3 and 7 percent by blend weight.

SERIAL NO. 10/005,846
ART UNIT 1771

IX. EVIDENCE APPENDIX

1. Copy of the Translation of Japanese Application JP10-017694 submitted with Appeal Brief of June 13, 2005 (pages 24-42)

2. Copy of Selected Passages from Synthetic Polymer Membranes, Copyright 1985, submitted with Appeal Brief of June 13, 2005 (pages 43-54)

TRANSLATION FROM JAPANESE

(19) Japanese Patent Office (JP) (12) Official Gazette for (11)
Japanese Unexamined

Laid-Open Patent

Patent Application

Applications (A)

(Kokai) No. 10-17694

(43) Disclosure Date: January 20, 1998

Class. Internal Office			
(51) Int. Cl. ⁶	Symbols	Registr. Nos.	F I
C 08 J 9/00	CES	C 08 J 9/00	CES A
9/28	CES	9/28	CES
H 01 M 2/16		H 01 M 2/16	P
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Request for Examination: Not filed Number of Claims: 3 FD
(Total of 7 pages [in original])

(21) Application No.: 8-194058	(71) Applicant: 000000033 Asahi Chemical Industry Co., Ltd.
(22) Filing Date: July 5, 1996	(72) Inventor: Takahiko Kondo (72) Inventor: Takuya Hasegawa
	(74) Agent: Takeshi Shimizu, Patent Attorney (and two others)

(54) [Title of the Invention] Microporous Polyethylene
Membrane

(57) [Abstract]

[Object] To provide a microporous polyethylene membrane that has better workability and results in better productivity, and that has high heat resistance capable of ensuring greater battery safety under stringent conditions.

[Means] A more heat-resistant microporous polyethylene membrane having a strain-hardening elongation viscosity, a gel fraction of less than 1%, and an average pore diameter of 0.001 to 0.1 μm ; a battery separator using it; and a battery using the battery separator.

[Merit] The better workability and productivity, and the higher heat resistance of the membrane allow more reliable batteries to be produced when it is used as battery separator.

[Claims]

[Claim 1] A more heat-resistant microporous polyethylene membrane, characterized by having a strain-hardening elongation viscosity, a gel fraction of less than 1%, and an average pore diameter of 0.001 to 0.1 μm .

[Claim 2] A battery separator featuring the use of a microporous polyethylene membrane according to Claim 1.

[Claim 3] A battery featuring the use of a battery separator according to Claim 2.

[Detailed Description of the Invention]

[0001]

[Technical Field to Which the Invention Belongs]

The present invention relates to a microporous polyethylene membrane suitable for use as a battery separator.

[0002]

[Prior Art]

Progress has recently been made in increasing the capacity of batteries, such as lithium ion batteries. As a result, an increasingly important issue has become battery safety during malfunctions such as short circuits. Microporous polyethylene membranes have been used as separators in such high capacity batteries, particularly lithium ion batteries. Such microporous polyethylene membranes are used because of their general properties, such as their mechanical strength and permeability, as well as their ability to develop the "Fuse Effect," where the separator melts to form a film covering the electrodes and cuts off the current when the battery internally overheats, thereby ensuring battery safety.

[0003]

Microporous polyethylene membranes are known to have a fuse temperature, which is the temperature at which the fuse effect takes place, of around 130 to 150°C. If for some reason the battery internally overheats, the current is shut down and the battery reaction is stopped when the fuse temperature is reached. However, the fuse effect can sometimes fail to take place in time when the temperature increases rapidly or the like. That is because the separator stretches and becomes broken due to the contracting force that is produced when the separator melts or due to the pressure persisting between the electrodes after the melt down, resulting in shorts between the positive and negative electrodes. Cross linked microporous polyethylene membranes have been used recently to endow separators with better heat resistance capable of ensuring battery safety even under more stringent conditions such as the above.

[0004]

Problems, however, with all conventional methods for cross linking microporous polyolefin membranes are that the gel content complicates processes such as stretching, the production efficiency is compromised, and so forth. Japanese Unexamined Patent Application (Kokai) 1-167344, for example, discloses a method for cross linking microporous polyolefin membranes with cross linkers, but the microporous polyolefin membrane obtained by this method contains an abundance of gel, complicating the stretching process and the like, and does not give a membrane with high strength.

[0005]

Japanese Unexamined Patent Application (Kokai) 56-73856 discloses a method for cross linking microporous polyolefin membranes by means of ionizing radiation, but the microporous polyolefin membrane obtained by this method also contains gel. Other problems are the need for a high energy process, which causes

the polyolefin to heat up while irradiated, so that the microporous membrane sometimes melts or shrinks. A necessary remedy is to separately carry out a number of treatments with lower energy.

[0006]

[Problems Which the Invention Is Intended to Solve]

An object of the invention is to provide a microporous polyethylene membrane that has better workability and results in better productivity, and that has high heat resistance capable of ensuring greater battery safety under stringent conditions.

[0007]

[Means for Solving the Abovementioned Problems]

As a result of extensive research undertaken to address the objects of the invention, the present invention was perfected upon the discovery that microporous polyethylene membranes characterized by specific thermal deformation behavior had higher heat resistance, with a gel fraction of less than 1%, resulting in better workability and productivity, as compared to microporous membranes lacking such behavior. That is, the first of the inventions is a microporous polyethylene membrane, characterized by strain-hardening during the measurement of elongation viscosity, and a gel fraction of less than 1%, preferably with an average pore diameter of 0.001 to 0.1 μm , as determined by a permeability method. The second of the inventions is a battery separator featuring the use of such a microporous polyethylene membrane. The third of the inventions is a battery featuring the use of such a battery separator.

[0008]

The invention is described in detail below. The microporous polyethylene membrane of the invention is described first. Although it is not clearly understood why the microporous polyethylene

membrane with strain-hardening properties and a gel fraction of less than 1% has high heat resistance, the heat resistance as determined in overcharging tests and breaking tests at elevated temperature, for example, can be dramatically improved in comparison to ordinary microporous polyethylene membranes lacking such strain-hardening properties. The method for endowing membranes with such strain-hardening properties is simple and does not compromise the workability or productivity of conventional membranes.

[0009]

The elongation viscosity is a physical constant with a considerable effect on melt tension during extension and deformation. It can be readily determined with a commercially available elongation viscosity meter (such as the Melten Rheometer by Toyo Seiki), and is normally expressed as a function of strain rate and time. As illustrated in Figure 2, the elongation viscosity of a molten microporous polyethylene membrane which normally contains no gel increases, when stretched at a constant strain rate from a relatively fixed point, until it is dependent on the strain rate, and then tends to decrease precipitously as it approaches breakage. This type of breakage is referred to as ductile fracture.

[0010]

As illustrated in Figure 1, on the other hand, the elongation viscosity of the molten microporous polyethylene membrane of the invention increases longer than the normal type when stretched under the same conditions, tending to increase at a linear or greater rate near the breaking point until sudden breakage. This type of breakage is referred to as elastic break. These properties indicate strain-hardening properties. Details on elongation viscosity can be found, for example, in Kiyohito Koyama, *Journal of*

the Japanese Society of Rheology, 19, 174 (1991). The gel fraction is determined based on ASTM D2765. The gel fraction in the invention is less than 1%. A gel fraction of 1% or more makes processes such as stretching more difficult and lowers productivity.

[0011]

The heat resistance of a separator made of the microporous membrane of the invention is comprehensively evaluated in accelerated tests involving heating tests as well as external short and overcharging tests on batteries assembled using the separator. As a result of detailed study of the breaking behavior of the membrane after melting, the inventors found that the results of the accelerated tests were strongly correlated to the break time in silicon oil at 160°C.

[0012]

That is, the microporous polyethylene membrane of the invention has a break time of at least 20 seconds in 160°C silicon oil. Such membranes passed all of the above accelerated tests. Conventional microporous polyethylene membranes, on the other hand, all failed one or more of the accelerated tests, with a break time of 20 seconds or less, which was consistent with the results of the accelerated tests. That is, a characteristic feature of the microporous polyethylene membrane of the invention is the break time in 160°C silicon oil.

[0013]

The microporous polyethylene membrane of the invention thus has high heat resistance, but with an air permeability of no more than 2000 seconds, as determined on the basis of 25 μ , and a

breaking strength of at least 500 kg/cm², resulting in far better heat resistance as well as mechanical strength and permeability than conventional microporous polyethylene membranes. The polyethylene used in the invention should be high density polyethylene, which is a crystalline polymer based on ethylene. Blends with no more than 30% polyolefin, such as polypropylene, medium density polyethylene, linear low density polyethylene, low density polyethylene, and EPR may also be used.

[0014]

The weight average molecular weight of the polyethylene should be 100,000 to 4,000,000, preferably 200,000 to 1,000,000, and even more preferably 200,000 to 700,000. A molecular weight under 100,000 tends to result in breakage during stretching, while more than 4,000,000 will complicate the manufacture of hot solution. The weight average molecular weight may be adjusted to within the desired range by blending polyethylenes of different molecular weight, by multiple stage polymerization, or the like. The membrane should be 1 to 200 μ m thick, and preferably 10 to 50 μ m thick. Less than 1 μ m will result in unsatisfactory mechanical strength, while more than 200 μ m will cause problems when attempting to make lighter, more compact batteries.

[0015]

The air permeability should be 20 to 80%, and preferably 30 to 60%. Less than 20% will result in poor permeability, while more than 80% will not result in satisfactory mechanical strength. The mean pore diameter should be 0.001 to 0.1 μ m, preferably 0.005 to 0.5 μ m, and even more preferably 0.01 to 0.03 μ m. A mean pore diameter under 0.001 μ m will result in poor permeability, while more than 0.1 μ m will slow down the interruption of the current

through the fuse effect, with a risk of short circuits caused by deteriorating electrolyte or precipitated dendrites.

[0016]

A method for producing the microporous polyethylene membrane of the invention is described below. The method comprises the following three steps of forming the membrane, stretching it, and extracting it.

Forming the Membrane

A polymer gel, which is an intermediate in the invention, is produced by dissolving polyethylene in a plasticizer at or over the melting point to produce a hot solution which is then cooled to no more than the crystallization temperature. The plasticizer referred to here is an organic compound capable of forming a homogenous solution with polyethylene at a temperature no greater than the boiling point. Specific examples include decalin, xylene, dioctyl phthalate, dibutyl phthalate, stearyl alcohol, oleyl alcohol, decyl alcohol, nonyl alcohol, diphenyl ether, n-decane, n-dodecane, and paraffin oil, paraffin oil and dioctyl phthalate are preferred. The proportion of plasticizer is not particularly limited, but is preferably 20% to 90%, and more preferably 50% to 70%. Less than 20% will interfere with achieving a suitable porosity, while more than 90% will result in a lower viscosity which will complicate continuous formation.

[0017]

The polymer gel is formed into a sheet with a thickness in the tens of μm to tens of mm. This is the starting sheet, and the step for producing it is referred to as the membrane-forming step. The method for forming the membrane is not particularly limited. An example is to feed the plasticizer and high density polyethylene powder to an extruder where the ingredients are melt kneaded at

about 200°C, and to then cast the mixture from a common coat-hanger die onto a cooling roll, thereby continuously forming membranes.

[0018] Stretching Step

The starting sheet is then stretched at least uniaxially to produce an oriented membrane. The stretching method is not particularly limited. Tenters, rolls, calendaring, and the like can be used. Biaxial stretching with tenters is preferred. The stretching temperature can range from ambient temperature to the melting point of the polymer gel, preferably from 80 to 130°C, and even more preferably from 100 to 125°C. The draw ratio should be 4 to 400-fold, preferably 8 to 200-fold, and even more preferably 16 to 100-fold, based on area. A draw ratio of less than 4-fold will not produce satisfactory separator strength, while more than 400-fold will make stretching difficult and will result in a lower porosity, etc.

[0019] Extraction Step

The plasticizer is then extracted from the drawn membrane to produce a microporous membrane. The extraction method is not particularly limited. When paraffin oil or dioctyl phthalate are used, they can be extracted with an organic solvent such as methylene chloride or methyl ethyl ketone (MEK), and then removed when heated and dried at a temperature no greater than the fuse temperature. When a low boiling compound such as decalin is used as the plasticizer, it can be removed by being heated and dried at a temperature no greater than the fuse temperature. In either case, the membrane should be restrained to prevent adverse effects on physical properties caused by membrane shrinkage. To endow the membrane with strain-hardening properties, a treatment with an organic peroxide should be performed during the membrane-forming

step, or treatment with ionizing radiation should be performed after any step.

[0020] Treatment With Organic Peroxide

A certain amount of an organic peroxide is added to the polyethylene or plasticizer, the ingredients are melt kneaded to produce a hot solution at conditions under which the peroxide does not substantially decompose, the hot solution is heated to the temperature at which the organic peroxide decomposes, and it is cooled to at least the polyethylene crystallization temperature, resulting in a peroxide-treated starting sheet. A microporous polyethylene membrane with strain-hardening properties can be produced through the stretching and extraction steps.

[0021]

The expression "peroxide does not substantially decompose" means that the active oxygen of the peroxide does not fall below $\frac{1}{2}$ during the time until a homogenous hot solution is prepared from the polyethylene, plasticizer, and organic peroxide. For example, if it takes 10 minutes to melt knead the ingredients, they should be melt kneaded at a temperature no greater than one resulting in a peroxide half life of 10 minutes, so that a homogenous hot solution can be prepared without the peroxide substantially decomposing. The half life is the time in which the amount of active oxygen reaches falls to $\frac{1}{2}$ when a benzene solution of 0.1 mol/L organic peroxide is allowed to decompose at a given temperature.

[0022]

The organic peroxides referred to here are peroxy ketals, dialkyl peroxides, peroxy esters, and the like with a half life of 1 minute or more at 150°C. Examples include α, α' -bis (t-butylperoxy)diisopropyl benzene, dicumyl peroxide, 2,5-dimethyl-2,5-bis (t-butylperoxy)hexane, t-butyl cumyl peroxide, di-t-butyl

peroxide, and 2,5-dimethyl-2,5-bis (t-butylperoxy)hexane-3. The proportion of the organic peroxide is not particularly limited, but is preferably 0.001% to 1%, and more preferably 0.01% to 0.5%. Less than 0.001% will result in unsatisfactory heat resistance, while more than 1% will result in insoluble gel components in the plasticizer, making it difficult to process the solution into a uniform membrane.

[0023]

Polyfunctional monomer may be added in a proportion no greater than 1%. Examples of polyfunctional monomers include divinyl benzene, diallyl phthalate, triallyl cyanurate, and triallyl isocyanurate. For example, a plasticizer in which the organic peroxide has been dissolved and high density polyethylene powder can be fed to an extruder, they can be melt kneaded at a temperature at or over the polyethylene melting point but no greater than one resulting in an organic peroxide half life of 10 minutes, and the hot solution can be cast onto a cooling roll from a common coat-hanger die heated to at least a temperature at which the organic peroxide half life will be 10 seconds, so as to continuously form membranes.

[0024] Electron Beam Treatment

The material can be endowed with strain-hardening properties by ionizing radiation treatment after any of the steps in the method for producing conventional microporous polyethylene membranes noted above. Treatment after extraction by ion beam treatment is preferred. The radiation during ion beam treatment should be 0.1 to 10 Mrad, and preferably 1 to 5 Mrad. Too little radiation will not improve the heat resistance enough, while too much will cause the microporous polyethylene membrane to be heated by the ion beam energy, so that the membrane sometimes melts or

shrinks. The strain-hardening properties can thus be readily provided without significantly affecting normal manufacture and productivity.

[0025]

[Embodiments of the Invention]

Embodiments of the invention are described in detail below. The following tests were conducted in the examples.

1) Membrane Thickness

Measured using a dial gage (Peacock No. 25 by Ozaki Seisakusho).

2) Porosity

This was determined by the following equation from the volume and weight of 20 cm square samples.

$$\text{Porosity (\%)} = \{ \text{volume (cm}^3\text{)} - \text{weight (g)}/0.95\} / \text{volume (cm}^3\text{)} \times 100$$

[0026] 3) Mean Pore Diameter

When an aqueous solution of 0.05 wt% pullulan (by Showa Denko) was circulated at a differential pressure of 0.5 kg/cm², the concentration of pullulan contained in the filtrate was determined from the differential refractive index. The mean pore diameter (μm) was calculated using the following equation from the molecular weight M of pullulan at 50% inhibition and the intrinsic viscosity {η} of the same aqueous solution.

$$[\eta] M = 2.1 \times 10^{11} \left(\left(\frac{d}{2} \right)^4 \right)^{1/3}$$

4) Gel Fraction

This was determined by the following equation as the ratio of the post-extraction residual mass relative to sample mass prior to extraction based on the change in weight upon the extraction of

components solubilized after 12 hours in boiling para-xylene based on ASTM D2765.

Gel fraction (%) = residual mass (g)/sample mass (g) × 100

[0027] 5) Puncture Strength

A puncture test was conducted at a puncture speed of 2 mm/sec with a needle tip radius of 0.5 mm using a KES-G5 Handy Compression Tester by Kato Tech. The greatest puncture load was considered the puncture strength (g). The puncture strength was multiplied by the membrane thickness (μm)/25 (μm) to calculate the puncture strength in terms of 25 μ .

6) Air Permeability

This was determined with a Gurley air permeability meter based on JIS P-8117. The air permeability was multiplied by membrane thickness (μm)/25 (μm) to calculate the air permeability in terms of 25 μ .

[0028] 7) Elongation Viscosity

The microporous membranes were dipped in 150°C silicon oil to relax the orientation, and the elongation viscosity was determined at a strain rate of 0.1/sec using a melt elongation flow measuring device (Melten Rheometer by Toyo Seiki). The presence or absence of strain-hardening properties was determined by the type of breakage. For example, stretching a conventional microporous polyethylene membrane results in neck-in about midway through in the sample, with a precipitous decrease in the elongation viscosity at a certain time before breakage (ductile fracture), whereas the elongation viscosity of microporous polyethylene membranes endowed with strain-hardening properties increases continuously until breakage (elastic break).

8) Membrane Break Test

A microporous polyethylene membrane was secured between two stainless steel washers with an outside diameter of 25 mm, this was held down at four peripheral points by clips, and it was dipped in 160°C silicon oil (KF-96-10CS, by Shin-Etsu Kagaku). Membranes which broke within 20 seconds, as determined by macroscopic assessment, were rated x, those which did not break were rated O.

[0029] 9) Overcharging Test

Lithium ion batteries were produced using LiCoO_2 as the positive electrode active material, graphite and acetylene black as the conductor, and fluorine rubber as the adhesive, resulting in an 88:7.5:2.5:2 weight ratio mixture of LiCoO_2 :graphite:acetylene black:fluorine rubber, which was applied in the form of a dimethyl formamide paste onto aluminum foil and dried. The resulting sheet was used as the positive electrode. A 95:5 weight ratio mixture of needle coke and fluorine rubber was applied in the form of a dimethyl formamide paste onto copper foil and dried. The resulting sheet was used as the negative electrode. Lithium borofluoride was adjusted to a concentration of 1.0 M in a propylene carbonate and butyrolactone solvent mixture (volumetric ratio = 1:1) as the electrolyte. The batteries were charged for 5 hours at 4.2 V, and were then overcharged at a constant current. The overcharging caused the interior of the batteries to heat up. The current was shut down when the fuse temperature was reached. Samples in which no current was restored 1 hour or later were rated O. Because these were accelerated tests, they were conducted without any of the safety features such as PTC elements which are normally set up in actual batteries.

[0030] Example 1

40 parts high density polyethylene with a weight average molecular weight of 250,000, 60 parts paraffin oil (P350P by

Matsumura Petroleum), and 0.2 part dicumyl peroxide (150°C half life about 10 min, 200°C half life about 7 sec) were kneaded for 5 min at 150°C and 50 rpm in a batch type melt kneader (Labo Plastomill by Toyo Seiki). The resulting kneaded mixture was molded with a 200°C heated press, heated as such for 10 minutes, and then cooled with a water-cooled press, giving a 1000 μ m thick starting sheet. This was drawn at 120°C to a factor of 6 \times 6 using a simultaneous biaxial stretching machine (by Toyo Seiki), and the paraffin oil was then extracted with methylene chloride. The properties of the resulting microporous polyethylene membrane are given in Table 1.

[0031] Example 2

A microporous polyethylene membrane was produced in the same manner as in Example 1 except that 0.8 part dicumyl peroxide was used. The properties of the resulting microporous polyethylene membrane are given in Table 1.

Comparative Example 1

A microporous polyethylene membrane was produced in the same manner as in Example 1 except that no organic peroxide was added. The properties of the resulting microporous polyethylene membrane are given in Table 1.

Comparative Example 2

An attempt was made to produce a microporous polyethylene membrane in the same manner as in Example 1 except that 6 parts organic peroxide was added, but considerable stretching stress caused the membrane to break, and the membrane could not be processed to the required draw ratio.

[0032]

[Table 1]

	Example 1	Example 2	Comp. Ex. 1	Comp. Ex. 2
membrane thickness (μm)	25	28	24	--
porosity (%)	40	38	45	--
pore diameter (μm)	0.03	0.02	0.04	--
puncture strength (g/25 μ)	400	450	300	--
air permeability (sec/25 μ)	620	710	470	--
gel fraction (%)	0	0	0	20
strain-hardening	yes	yes	no	--
break test (160°C)	0	0	x	--

[0033] Example 3

40 parts high density polyethylene with a weight average molecular weight of 250,000, 60 parts paraffin oil (P350P by Matsumura Petroleum), and 0.4 part dicumyl peroxide were kneaded at 150°C in a 35 mm biaxial extruder, and the kneaded mixture was cast from a 200°C coat-hanger die (1400 μm lip interval) onto a cooling roll adjusted to 30°C to produce a 1400 μm thick starting sheet. The sheet was stretched at 120°C to a factor of 7×7 using a simultaneous biaxial stretching machine, and the paraffin oil was then extracted with methylene chloride. The properties of the resulting microporous polyethylene membrane are given in Table 2.

[0034] Example 4

40 parts high density polyethylene with a weight average molecular weight of 250,000 and 60 parts paraffin oil (P350P by Matsumura Petroleum) were kneaded at 200°C in a 35 mm biaxial extruder, and the kneaded mixture was cast from a coat-hanger die (1400 μm lip interval) onto a cooling roll adjusted to 30°C to produce a 1400 μm thick starting sheet. The sheet was stretched to a factor of 7×7 using a simultaneous biaxial stretching machine, and the paraffin oil was then extracted with methylene chloride. The extracted membrane was irradiated with a 3 Mrad ion beam in a

nitrogen atmosphere with an oxygen concentration of 50 ppm. The accelerated voltage was 150 kV. The properties of the resulting microporous polyethylene membrane are given in Table 2.

Comparative Example 3

A microporous polyethylene membrane was obtained in the same manner as in Example 2 except that no organic peroxide was added. The properties of the resulting microporous polyethylene membrane are given in Table 2.

[0035]

[Table 2]

	Example 3	Example 4	Comp. Ex. 3
membrane thickness (μm)	23	29	29
porosity (%)	37	48	40
pore diameter (μm)	0.02	0.04	0.04
puncture strength (g/25 μ)	600	550	620
air permeability (sec/25 μ)	750	450	470
gel fraction (%)	0	0	0
strain-hardening	yes	yes	no
break test (160°C)	0	0	x
overcharge test 2A	0	0	break
3A	0	0	break

[0036]

[Merit of the Invention]

Because the microporous polyethylene membrane of the invention has high heat resistance, its use as a battery cell separator in particular results in better safety in terms of the fuse effect, with no restoration of current due to membrane breakage. This allows safer batteries to be provided.

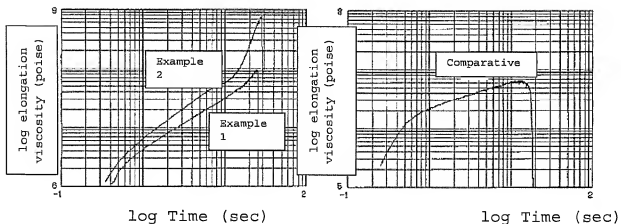
[Brief Description of the Figures]

Figure 1 illustrates the relationship between time (sec) and elongation viscosity (poise) in the microporous polyethylene membranes having strain-hardening properties in Examples 1 and 2.

Figure 2 illustrates the relationship between time and elongation viscosity in the microporous polyethylene membrane lacking strain-hardening properties in Comparative Example 1.'

Figure 1

Figure 2



[Amendments to the original Japanese text have been incorporated in the translation.]

SYNTHETIC POLYMERIC MEMBRANES

A Structural Perspective

Second Edition

ROBERT E. KESTING
IRVINE, CALIFORNIA

A Wiley-Interscience Publication

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In many respects the Celgard® process, in which amorphous films or fibers are extended from the melt and partially reduced by simply stretching the inhibited articles in the solid state, represents the ideal baseline as the manufacturing of microporous membranes is concerned. No solvents are required. Polypropylene (PP), the basic substance and is available in a large number of specially grades. Furthermore, production rates are believed to be high. Although the process is limited to certain stillite pore sizes—generally $\sim 0.2 \mu\text{m}$ in length and $0.02 \mu\text{m}$ in width—and porosities $\sim 40\%$, this lacks the extremely broad range of pore sizes and void volumes encompassed by phase-inversion membranes, nevertheless, for many applications such structures are extremely useful.

The Celgard® process is comprised of a number of interrelated steps:

1. Extrusion of film or fiber under conditions of relatively low melt temperature and high melt stress. In other words, the takeup speed is considerably greater than the extrusion rate. Under these conditions the PP molecules align themselves in the formation of folded-chain row lamellar microfibrils which are believed to nucleate the fibrillar structure.^{6,7}

2. The row lamellae are consolidated by annealing at a temperature just below the T_m . Segmental motion is permitted which results in crystalline growth and densification as well as folding of the polymer chains at crystalline surfaces but prevents melting which would tend to relax the lamellae and allow them to assume the more random spherulite formation which obtains under unstressed conditions. The lamellae are separated from one another by amorphous regions composed of atactic blocks or otherwise noncrystalline material in the 50% crystalline polymeric stress-strain properties (Fig. 8.1) and greater elasticity (Fig. 8.2) than comparable objects prepared from unstressed and unannealed PP. The morphology of the row amounts to controlled crumpling, the dense precursor objects are stretched $50\text{--}300\times$ at a temperature above the initial annealing temperature but below the T_m . This deforms the amorphous regions between the lamellae into fibrils and results in a porous interconnecting network of stillite voids in the machine direction (Fig. 8.3b). The dimension of the pores are defined by the drawn fibrils. They are $0.4 \mu\text{m}$ in length and $0.04 \mu\text{m}$ in width for Celgard® 2500. Porosity is 40% and pore density one patent call for stretching at room temperature. The objects become noticeably more opaque at this point and the apparent density decreases (Fig. 8.4). The extent of stretching controls both pore size and pore size distribution (Fig. 8.5). Films which are stretched only $100\times$ have a bimodal distribution of pore sizes with many stretched $300\times$ because the latter contain primarily pores below $0.1 \mu\text{m}$. Stretching

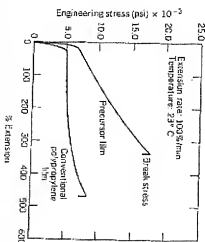


FIGURE 8.1. Stress-strain properties of precursor film prepared from isotactic polypropylene, α -methylstyrene, and α -methylstyrene, prepared from isotactic polypropylene, α -methylstyrene, and α -methylstyrene. (Copyright American Chemical Society, 1974.)

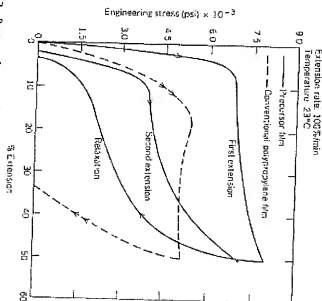


FIGURE 8.2. Recovery of precursor film from which stable deformation from thermal stability, α -methylstyrene, and α -methylstyrene, prepared from isotactic polypropylene, α -methylstyrene, and α -methylstyrene. (Copyright American Chemical Society, 1974.)

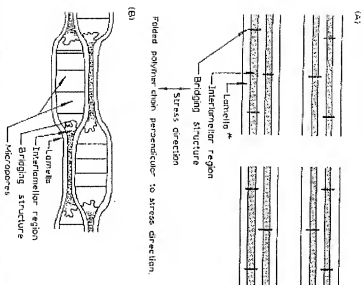


FIGURE 8.3. Schematic representation of lamellar structure morphology of (a) Celgard[®] precursor (as received and unstretched film), and (b) microporous Celgard[®] film after stretching (from Bercenstein et al.¹; reproduced with permission from *Industrial Engineering Chemistry, Product Research Development* © 1974 American Chemical Society).

in excess of 300% results in a precipitous loss of porosity. Finally, because the newly stretched porous films are still elastic, they are set at a temperature just below the T_m while still under tension. This minimizes subsequent loss of porosity due to creep.

The surface structure of Celgard[®] 2500 shows rows of elongated pores separated by unrestricted lamellae (Fig. 8.6). The stretched lamellar pores are aligned horizontally, that is, in the original machine direction. Fibrous bridging structures separate the pores from each other and the rows of pores alternate with the unstretched lamellar crystallites. The cross-sectional view of the bulk structure indicates the presence of a 0.5- μ m thick surface region where density is greater than that of the substructure (Fig. 8.7).

The three-dimensional composite view of Celgard[®] 2500 (Fig. 8.8) clearly shows the pores defined by drawn fibrils to be silt with the major axes parallel to the

STRETCHED SEMICRYSTALLINE FILMS 2

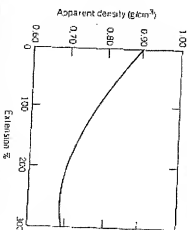


FIGURE 8.4. Apparent density of microporous polypropylene film as a function of extension (from Bercenstein et al.¹; reproduced with permission from *Industrial Engineering Chemistry, Product Research Development* © 1974 American Chemical Society).

machine direction and the film surface. The longest dimension of the pore depends on the distance between the lamellar microcrystallites.

Although Celgard[®] is thin (0.025 cm thick) it can be laminated to itself to increase its stiffness and ease of handling. Its physical properties, reflecting the fold line endurance characteristics of unmodified PP, are outstanding (Table 8.5). The films with a high surface area (Table 8.6).

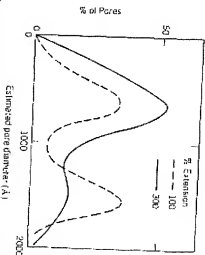


FIGURE 8.5. Pore-size distribution in microporous polypropylene films (from Bercenstein et al.¹; reproduced with permission from *Industrial Engineering Chemistry, Product Research Development* © 1974 American Chemical Society).

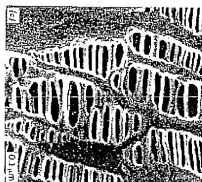
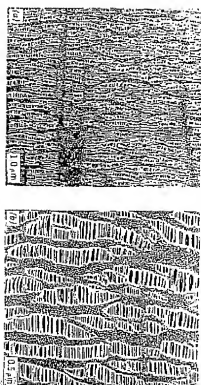


FIGURE 8a. High-resolution secondary electron images of Celgard® 2500 surface (from Sarda et al.¹⁰).

Celgard® is available in both flat and hollow-fiber form. Celgard® 2400 and Celgard® 2500 are hydrophobic films with effective pore size (pore-width distributions) of 0.02 and 0.04 μm , respectively. Two- μm forms are also available as various composite laminates to nonwoven polypropylene fabrics. The corresponding hydrophilic (surfactant-containing) grades are Celgard® 3400 and Celgard® 3500.

The two hydrophobic microporous hollow-fiber grades, Celgard X-10 and X-20, differ in porosity, ~20 and 40%, respectively, but not in effective pore size (0.05 μm). They both have MW cutoffs of approximately 100,000 daltons. Celgard X-10 is available in 100, 200, and 240- μm ID 25- μm wall thickness. One particular use where these fibers are expected to dominate is in hollow-fiber blood oxygenators. Gore-Tex® microporous poly(tetrafluoroethylene) (PTFE), is one of the most





FIGURE 07. (Continued)

important of the porous membranes manufactured by process called the phase-inversion. Gore-Tex[®] also resembles Caloguard[®] in that they both consist of ethylene tetrafluoropolymer (ETFE) and polytetrafluoroethylene (PTFE) and are chemically similar to the polypropylene (PP) and polyethylene (PE) based membranes. The main difference is that the latter are not designed to introduce pores. First, the fact that the silts in Gore-Tex[®] are not always removed by the membrane is not a problem for the membrane. Second, the fact that the same PTFE cannot be melt extruded, a highly ($\sim 38.5\%$) crystalline polymer of 500,000 MW and low ($\sim 1.0\%$) flexible structures, Teflon[®] 60A, is mixed together with 15–25% of a fluorine such as naphthalen or ketone and

TABLE 8.5 TYPICAL PHYSICAL PROPERTIES OF CELGARD FILM^a

Property	Value	Test Method
Tensile strength, MPa ^a	20,000 psi	ASTM D682
TD ^b	2,000 psi	ASTM D682
Tensile modulus, MPa	2×10^5 psi	ASTM D682
Elongation, %	40%	ASTM D682
Tear initiation, MPa	1 lb	ASTM D1004
MFT fold endurance	10 ⁶	ASTM D641
Molten burst	20 points	ASTM D774

³From Bittmann et al.¹ Reprinted with permission from Industrial Engineering Chemistry Product Research Development, © 1983 American Chemical Society.

^aTD = transverse to matrix

TABLE 8.6 COMPATIBILITY OF CELGARD FILM WITH VARIOUS COMPOUNDS^a

Acidic		Illigenerated Polyimides	A
H ₂ SO ₄ (conc'd)		Carbon tetrachloride	A
Alcohols		Tetraethoxyethylene	A
Ethyl alcohol		(perchloroethylene)	A
Ethylen glycol			A
Isopropyl alcohol		Hydrocarbons	A
Ether alcohols		Benzene	B
Buryl Cellulose		Phenane	B
(2-butyracrylate)		Toluene	B
Methyl Cellosolve		Ketones	B
(2-methoxyethanol)		Acetone	A
Bases		Methyl ethyl ketone	A
KOH (40%)		Oil	A
Ethers		DOW-19 motor oil	E
1,4-dioxane		Miscellaneous	E
Fuels		N,N'-dimethylacetamide	A
Gaseoline		Nitrobenzene	B
Kerosene		Tetrahydrofuran	B
		Freon TF	B

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(no effect); B, slight swell; C, minimal swell, separation characteristics should be evaluated.

then man extruded. The lubricant is then removed by heating, after which the sheet is reduced in thickness by passing between calendar rolls at 100°C. Uniaxial or biaxial stretching is followed by stretching at 237°C. During the stretching process, the amorphous content increases and there is a "lock in" and strengthen the β phase in the stretched membrane. The Dorr-Tate process is versatile and capable of producing membranes with pore-size and porosity ranges which rival those of phase-inversion membranes (Table 8-7). Gore-Tex[®] membranes are also available in laminated composites with a variety of support substrates. They represent the most chemically inert and hydrophobic synthetic polymeric membranes and are unique in their ability to filter organic solutions and low inorganic acids and bases which are vital to the electronics industry.

8.3 SINTERED-PARTICLE MEMBRANES

Sintering refers to any change in shape undergone by a small particle or a cluster of particles of uniform composition when held at an elevated temperature.¹² In producing membranes by the sintering process, finely divided particles (spherical or fibrous in shape) are heated to a temperature at or below the glass-transition

TABLE 7.3 EFFECT OF RELATIVE HUMIDITY UPON PERMEABILITY AND PORE SIZE^a

Relative Humidity at 20°C (%)	Filtration Time ^b (sec)	Average Pore Diameter (nm)
80	25-40	~600
60	40-60	~500
40	60-80	~400

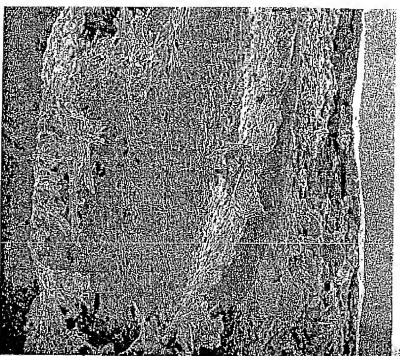
^aFrom Malar and Scheuermann⁴
For 200 mL H₂O/12.5 cm² at 70 cm Hg

TABLE 7.4 INFLUENCE OF CASTING SOLUTION WATER CONCENTRATIONS UPON PORE SIZE AND PERMEABILITY OF COLLOIDION MEMBRANES^a

Wt % Concentration of Casting Solution (%)	Filtration Time ^b (s)	Average Pore Diameter (nm)	Casting Solution Viscosity at 20°C (cp)
3.3	40	630	2011
0.4	800	30	1815
0.0 (in vac)	4000	15	1600

^aFrom Malar and Scheuermann⁴
~500 mL H₂O/12.5 cm² at 70 cm Hg

E 732 SEM photomicrograph of a cross section of a dry cellulose acetate membrane prepared from benzene (from Kesting et al.¹⁴ © 1983).



7.2 EQUIVALENT NONSOLVENT CONCENTRATIONS IN ACETONE AND LAKE SOLUTIONS^a FOR DRY-RO BLEND MEMBRANES OF CA AND THE TMC OF CA TRIMETHYLDECANOATE

Bleeding Point (°C)	Δbp (°C)	Nonsolvent Concentration (g BBA/bromination)	Permeability ^b Resistance ^c (gal/ft ² ·day)	Size Exclusion ^d (Å)
36	54	38	3.6	670
75	35	50	5.5	970

^adegree concentration, 80% w/vol; polymer ratio, 6:1 ALP-6/CA/TMA salt of CA; J. Monomer (made from E-38)-40 CA with D3-D5 (quaternary ammonium group); method, 100°C; time at 40-90 and 25 = 1°C.

ionally during drying and less likely to be wet — dry reversible. Since the dry process tends to employ more dilute solutions and less compatible pore formers both of which characteristics promote the formation of microgels than does the wet process, the former is more likely to produce microgels than the latter. However, there are many exceptions to this rule and it is possible both to produce microgels by a wet process and ultragels by a dry process.

7.3 THE WET PROCESS

The wet or combined evaporation-diffusion technique is that variation of the phase-reversion process in which a viscous polymer solution is either (1) allowed to partially evaporate after which it is immersed into a nonsolvent gelation bath where whatever is left of the solvent-pore-former system is exchanged for the nonsolvent; (2) is immersed directly into the nonsolvent gelation bath for the exchange of the solvent system for nonsolvent. The end products of the wet process are water-swollen membranes; moreover, the water content of membranes—the equivalent of porosity in the dry process—is a prime determinant of the functional performance characteristics. It is therefore fundamental to consider the effects of such variables

as casting-solution composition and environmental parameters in terms of their effects upon membrane water content.^{14,15}

A wet-process solution must be relatively viscous ($> 10^4$ cps) at the moment of immersion in the nonsolvent so that it will retain its integrity throughout gelation. When it is too fluid, the primary gel will be subject to disruption by the weight of the nonsolvent and the uneven forces brought about by the various currents which come into play during immersion. The requirement for high viscosity and hence high polymer concentration is in most cases inconsistent with the attainment of high porosity via the inclusion of nonsolvent pore formers. Therefore, when they are required, pore formers which are utilized in wet-process casting solutions are frequently chosen from the swelling agent—weak solvent side of the polymer-solvent interaction spectrum (Chapter 5). Moreover, the presence of pore formers within the casting solution prior to its immersion into a nonsolvent gelation bath is not a requirement of every wet-process solution. In many instances, particularly when nonsolvent solvents with a strong affinity for the nonsolvent in the gelation bath are utilized, the phase-inversion sequence Sol 1 → Sol 2 → gel is evoked by the simple act of immersion into nonsolvent. In such a case the nonsolvent bath represents an external source of incompatibility and a two-component solution (polymer + solvent) becomes in effect a three-component solution (polymer + solvent + insoluble pore former) as a result of the diffusion of the nonsolvent into, and the solvent out of, the nascent membrane gel.

The effect of the strong nonsolvent, water, may be influenced by other components of the casting solution. The presence of lyotropic salt swelling agents from the Hofmeister series causes the aggregation of water molecules about the electrostatic cations, thereby considerably modifying the properties of the water so affected.¹⁶ The result of this interaction is to change the role of water from that of a nonsolvent to that of a swelling agent (Table 7.5). Other polar nonsolvents such as the aliphatic alcohols function in much the same manner as water, except that their nonsolvent tendencies are less pronounced. The role of water in the atmosphere and in the solution to effect gross structural irregularities will be discussed later in this chapter.

The effects of increasing the concentration of the weak nonsolvent pore former, ethanol, in a casting solution containing CTA and acetone is to increase the porosity of the resultant membranes (Table 7.6, Figs. 7.13). (Because of their excellent solubility certain cellulosic polymers can be so formulated that their solutions require no special precautions to the rule that wet-process solutions require highly compatible pore formers). As the concentration of ethanol is increased, the values of δ_p decrease slightly and the values of δ_s increase appreciably, which has the effect of bringing the solution closer to the point of incipient gelation, that is, to the periphery of the solubility envelope. Since a solution which contains a high concentration of nonsolvent can be prepared to be of the Sol 2 type, close to gelation, its immersion into a nonsolvent bath and subsequent gelation will be accompanied by less gel contraction than would occur if the solution were further removed from the periphery of the solubility map. The result is that porosity and permeability increase as the concentration of pore former increases. Because the pore former is

TABLE 7.5 CASTING SOLUTION WATER-CONCENTRATION EFFECTS^a

Water Concentration (g/formulation) ^b	Swelling-Agent Concentration (g ZnCl ₂ /formulation) ^b	Description of Membrane	Wet Thickness of Unheated Membrane (mm) × 10 ²	Gravimetric Swelling Ratio of Unheated Membrane (wet wt/dry wt)	Rate of Water Transport (mL/cm ² day) ^c		Salt Retention (%)
					Deionized-Water Feed	0.6 M NaCl Feed	
0	0	Brittle, opaque (microgel)	5.8	1.47	< 1	—	—
5	0	Brittle, opaque (microgel)	6.4	1.77	< 1	—	—
10	0	Brittle, opaque (microgel)	7.1	1.99	< 1	—	—
15	0	Brittle, opaque (microgel)	8.0	2.35	< 1	—	—
0	5	Clear (ultragel)	8.7	2.53	24	16	90.3
5	5	Opalescent (ultragel)	9.0	2.79	34	22.8	97.2
10	5	Opalescent (ultragel)	9.2	2.85	72	48	98.5
15	5	Opalescent, opaque (ultra gel-microgel)	9.6	2.92	136	82	96.2

^a From Kessing et al.¹⁴, © 1965

^b Formulation: cellulose acetate, 22.2 g; acetone, 66.7 g (chloroform 25g, 0.75 mm)

^c Rate of water transport and salt retention at 102 atm are for heated membranes (86°C for 5 min).

TABLE 7.6 EFFECT OF SWELLING AGENT ETHANOL ON THE MEMBRANE WATER CONTENT

Membrane Code No.	Mixed Solvent	Ethanol (mol %)	Acetone (mol %)	Calculated δ		Membrane Water Content (wt %)
				δ_1	δ_2	
CA-24	20	80	4.99	4.21	50.7	50.3
CA-25	30	70	4.93	4.69	50.3	53.4
CA-22	40	60	4.86	5.20	53.4	61.2
CA-25	46.6	53.4	4.83	5.47	61.2	65.8
CA-21	50	50	4.79	5.75	65.8	

From Chuah and Chang,¹⁸ © 1975.

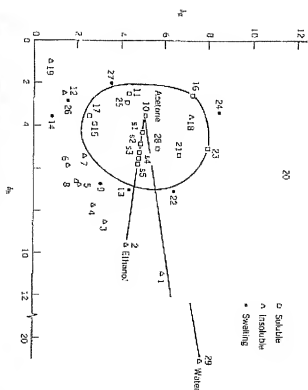


FIGURE 7.13. Solubility diagram for cellulose acetate-solvents near (1) methanol, (2) ethanol, (3) propanol, (4) butanol, (5) 1-octanol, (6) 1-octanol, (7) 2-octanol, (8) cyclohexane, (9) benzene, (10) acetone, (11) methyl ethyl ketone, (12) diethyl ether, (13) ethyl acetate, (14) diethyl ether, (15) tetrahydrofuran, (16) tetrahydrofuran, (17) ethyl acetate, (18) diethyl ether, (19) toluene, (20) formamide, (21) N,N-dimethyl formamide, (22) diethylamine, (23) dimethyl sulfoxide, (24) acetonitrile, (25) pyridine, (26) chloroform, (27) 1,2-dichloroethane, (28) zinc stearate, and (29) water (from Chuah and Chang¹⁸).

THE WET PROCESS

of a nonsolvent type, solution compatibility decreases with increasing ethanol content. This leads ultimately to increased diameters in the media of and consequently to greater opacity in the final membrane. It is worthy of note that it is only the insufficient Δ of 23°C between acetone and ethanol which precludes this solution from being a candidate for the dry process. If methyl formate (30°C) or propylene oxide (bp 33°C) had been employed as solvents in conjunction with ethanol as the pore former, this solution could have served in either a dry-process mode. If acetone had been utilized as a solvent in conjunction with ethanol (bp 97°C) or toluene (bp 108°C) as pore formers, the same would apply.

The effects of increasing the concentration of the solvent-type polymers, upon the porosity, optical, and permeability properties of the membranes are found in Table 7.7. In the first place, the utilization of this solvent and formamide as solvents, leads to the formation of a dense film. Since both are high-boiling solvents, formamide, which plasticizes the CA, gel as it evaporates. Increasing concentration of formamide in the acetone-formamide solvent system suggests that solvent power increases as well. Concurrent increases in thickness of formamide occupied with its strong affinity for solvating CA. After immersing in a reduced rate during which the aggregating mass is more amenable to the surface case of a more abrupt Sol 2 \rightarrow gel transition.

TABLE 7.7 PROPERTIES OF SOLS AND GELS FROM ACETONE-FORMAMIDE SOLUTIONS OF CA*

Formamide Concentration (mol %)	Sol Properties		Gel Properties			
	Viscosity at 25°C ($\times 10^3$)	Turbidity at 546 m μ ($\times 10^{-1}$)	Thickness (cm)	Wet wt (%)	Wet wt (%)	
0	0.895	1.6	38.7	36	1.71	No
10	0.942	0.9	33.2	43	2.10	No
20	0.948	0.6	—	46	2.01	No
30	0.965	0.5	20.7	74	3.44	1
40	—	0.45	7.8	86	3.90	3
50	—	0.45	1.4	94	4.40	13

Adapted from Kurata and Macosko,¹¹

* Vapored from Kesting and Macosko,¹⁷ 15 g 15-20-10 CA/100 mL solution.

nure and function of HF membranes (Table 7.8). Increasing temperature hastens the onset of gelation which in turn results in increased void size, degree of swelling, and permeability, and decreased permselectivity.

Increasing the evaporation (drying) time prior to immersion in the nonsolvent medium causes a decrease in cell size and porosity and hence a decrease in permeability (Table 7.9). Permselectivity first increases and then decreases owing to stress imposed on the skin layer and possibly also to some swelling and rehydrating of the skin as the solvent concentration in the nonsolvent bath increases.

The higher the affinity of the gelation medium for the components of the casting solution, the more gradual will be the Sol 2 → gel transition and the greater will be porosity in the final membrane. Thus the gelation of a CA solution in methanol will lead to a membrane of higher porosity than the gelation of the same solution in water. Methanol has greater affinity for CA than does water. Conversely, water is a stronger nonsolvent for CA than is methanol. Because the immersion of a casting solution in a strong nonsolvent such as water often leads to a skinned membrane it may be expedient, when a skinless membrane is desired, to immerse the casting solution into a nonsolvent solution which contains some solvent. Likewise, when a skinned membrane is available by any process, the skin may often be removed by immersing it into a nonsolvent/solvent solution. A closely related phenomenon known as *clearing* is utilized to collapse an opaque micro porous electrophoresis membrane into a clear dense film so that the electrophoretogram can be read on an optical densitometer without changing the spatial relationships between the various protein fractions. Here the reverse of the dry casting process is employed. Instead of utilizing a volatile solvent and a nonvolatile nonsolvent to gradually decrease compatibility, a volatile nonsolvent and a nonvolatile solvent are employed to gradually increase the affinity of the clearing solution for the membrane substance as drying progresses. Gravity does the rest as the softened but intact gel slowly collapses.

The structure which is at hand immediately following the Sol 2 → gel transition in the dry process is known as a primary gel. It is seldom isolated as such because with continued evaporation (\pm glycerol) and drying the completely consolidated membrane, known as the secondary gel, is ordinarily the only product which is encountered or of interest. This is not usually the case for the wet process, however. Here, after the viscous solution has been gelled by immersion and the solvent system has been removed from the gel, a primary gel membrane which is stable as such for an indefinite period is the result. Such a membrane is easily distinguished from the secondary gels which result after the primary structures have been subjected to various postformation treatments.

As was the case for the dry process, the control of primary gel structure by environmental and especially casting-solution variables permits far greater latitude in the regulation of ultimate structural and performance characteristics of wet phase-inversion membranes than does the modification of primary and secondary gels. Because the properties of the primary gel determine to a large extent those of its secondary counterpart, the former should be considered as the more fundamentally characteristic and important structure in any consideration of the effects of vari-

TABLE 7.8 GELATION-BATH TEMPERATURE EFFECTS^{a,b}

Gelation-Bath Temperature (°C)	Membrane Appearance	Intrinsic Viscosity [η] of Cellulose Acetate in Acetone-Water (66.7:100) ^c	Wet Thickness of Unheated Membrane [(mil) $\times 10^3$]	Gravimetric Swelling Ratio of Unheated Membrane (wet wt/dry wt)	Rate of Water Transport mL/cm ² day ^d		Salt Retention (%)
					Deionized-Water Feed	0.6 M NaCl Feed	
0	Opalescent	0.985	9.2	2.85	84	50	98.6
10	Opaque	0.960	14.0	3.80	83	50	97.1
25	Opaque	0.05	22.8	5.80	90	58	90.1
40	Opaque	0.745	31.0	6.98	118	74	81.1

^a From Kesting et al.¹⁴, © 1965

^a From Kesling et al.¹⁴, © 1985.

^b Casting-solution composition: cellulose acetate, 22.2 g; acetone, 66.7 g; water 10.0 g; ZnCl₂, 5.0 g (doctor-blade gap, 0.25 mm).

^c Measured at the corresponding gelation-bath temperature.

^d Rate of water transport and salt retention at 102 atm pressure for heated membranes (86°C for 5 min).

TABLE 7.9 DRYING TIME EFFECTS^{a,b}

Drying Time (min) ^c	Description of Membrane	Wet Thickness of Unheated Membrane (mm) × 10 ²	Gravimetric Swelling Ratio of Unheated Membrane (wet dry/dry wt)	Rate of Water Transport (ml/cm ² day) ^d		Salt Retention (%)
				Deionized Water Feed	0.6 M NaCl Feed	
1	Opaque-opalescent (microgel blending into ultragel)	13.9	2.88	116	72	98.0
3	Opalescent (ultragel)	12.2	2.98	84	50	98.6
5	Opalescent (ultragel)	10.2	2.65	86	54	98.8
10	Opalescent-clear (ultragel)	8.5	2.41	80	50	96.3
20	Clear (ultragel)	5.8	1.75	72	50	75.1
30	Clear (ultragel)	5.3	1.60	50	36	71.5

^aKessing et al.¹⁴, © 1965.^bCasting-solution composition: cellulose acetate, 22.2 g; acetone, 66.7 g; water, 10.0 g; ZnCl₂, 3.0 g (doctor-blade gap, 0.25 mm).^cDrying time—interval between casting at -11°C and immersion into gelation bath (0°C).^dRate of water transport and salt retention at 102 atm pressure for heated membranes (86°C for 5 min).

tion in fabrication parameters, for example, casting-solution composition, upon performance characteristics. Once a primary gel has been formed, it may be utilized as such (particularly for low-pressure applications), or it may be subjected to various physical and/or chemical treatments for conversion into a secondary gel which may be more suitable for a given end use.

Physical modifications of primary gel structures can be effected either to increase or to decrease the porosity (degree of swelling, void volume, water content, etc.), pore size, permeability, and permselectivity. The technique utilized to produce porous membranes from dense films can be used to effect an increase in porosity. In this variation of Brown's⁸ technique (Chapter 8), an already porous primary gel is immersed in a swelling medium. To set the secondary gel in its more expanded condition the swelling medium is removed, either by exchange with nonsolvent (nonsolvent-swelling-agent miscibility is essential) or by simple evaporation.

Since this technique adds another step to the fabrication process and is complicated by the swelling of low-molecular-weight polymer from the primary gel by the swelling medium, it is usually circumvented by the reformulation of the casting solution to produce a primary gel with an initially higher void volume. It is frequently encountered, however, as an undesirable factor in the permeation of certain organic solutes which interact with and swell the membrane, thereby altering initial pore characteristics and permeability. Of much greater practical importance are physical alterations of the primary gel structure to effect decreases in porosity. The most important reasons to this end are thermal annealing, pressurization, and solvent shrinking.

Annealing a porous membrane (particularly one which contains a nonswellable capable of functioning to some extent as a plasticizer) results in a diminution of void volume and permeability and, because pore size is generally decreased as well, an increase in permselectivity. The reason for this can be seen on the basis of the macromolecular, with the result that polar groups on the same and/or on neighboring molecules will approach one another closely enough to form virtual cross-links by dipole-dipole interactions. These cross-links tend to decrease chain mobility and, in a nonsolvent medium, are irreversible because of the inability of the nonsolvent to solvate and therefore intervene between the polar groups to effect dissolution. A continuous effect is the loss in water content and void volume with increasing temperature (Fig. 7.14). Water is lost from the primary gel during annealing, both because of the formation of virtual cross-links and because of the discontinuous effect is the dramatic increase in permselectivity (salt rejection) which is observed when cellulose acetate membranes are heated above 68.6°C, the glass transition temperature (Fig. 7.15). In fact, not only two discontinuities are found on the permselectivity versus annealing temperature curve for cellulose acetate desalination membranes. The first signals an increase, and the second a decrease, in permselectivity. The increase in permselectivity is due to the decrease in

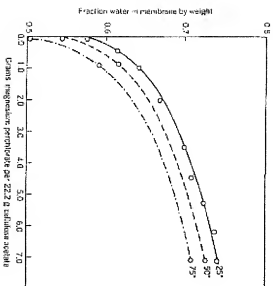


FIGURE 714. Membrane-water content as a function of temperature. (from Keating et al., 1, © 1965).

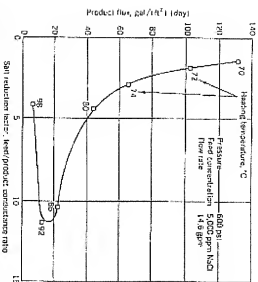


FIGURE 715. Permeability versus permeability for Lab-Solvent membrane installed at various temperatures.

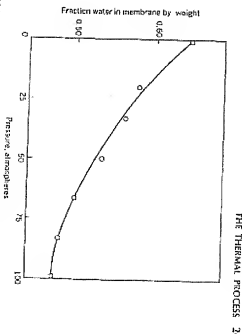


FIGURE 716. Membrane-water content as a function of pressure. (from Keating et al., 1).

interpretation, may be attributed to the attainment of the critical interchain spacing or pore diameter, whereas the decrease may be related to disruption in the uniformity of these spacings owing to either alignment of polymer chains in the glassy state in some regions at the expense of steric-induced removal of polymer chains from one another in others.

Whereas heating causes shrinkage in three dimensions, the application of pressure causes shrinkage primarily in one dimension, namely in the phase perpendicular to the surface. Two stages may be distinguished in the shrinkage of porous membranes under pressure (Fig. 7.16): (1) The rapid loss of void volume by the slower, more gradual loss of void volume by the comparatively dense skin layer. Inasmuch as the skin layer more closely approaches the structures of the bulk polymer, it is to be expected that significant compaction of this layer will require pressures in excess of the compressive yield point.

7.4 THE THERMAL PROCESS

A significant recent development in the technology of phase-inversion membranes is the invention of the thermal process by Castro.¹⁹ The thermal process is applicable to a wide range of polymers, which because of their poor solubility, are otherwise inaccessible to the phase-inversion approach. In essence, the thermal process utilizes a latent solvent, that is, a substance which is a solvent at elevated (-220°C) temperatures and a nonsolvent at lower temperatures, and thermal energy to produce a solid which on cooling inverts into a solid and on further cooling, gels. The reason for the incompressibility which produces Gel 7.1 is the

SERIAL NO. 10/005,846
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X. RELATED PROCEEDINGS APPENDIX

1.	Application serial Number 10/005,846 was filed	December 3, 2001.
2.	Status Inquiry Filed	May 7, 2003
3.	First Official Action mailed	June 24, 2003
4.	First Amendment filed	September 16, 2003
5.	Final Rejection Mailed	November 25, 2003
6.	FIRST Notice of Appeal and Appeal Brief filed	February 24, 2004
7.	Prosecution reopened, Official Action mailed	April 21, 2004
8.	Applicant Filed a response	July 18, 2004
9.	Non-final Action filed	September 28, 2004
10.	Response to Non-final action	November 24, 2004
11.	Mail Misc Communication	January 10, 2005
12.	Response to Non-final action	January 14, 2005
13.	IDS Filed	January 24, 2005
14.	Second Final Rejection	March 11, 2005
15.	SECOND Notice of Appeal and Appeal Brief filed	June 13, 2005
16.	Examiner's Answer	July 20, 2005
17.	Reply Brief	September 19, 2005
18.	Panel Remand to Examiner by BPAI	September 8, 2006
19.	Examiner's Answer	November 3, 2006
20.	Reply Brief	December 8, 2006

This appeal is the second appeal in this case.

This case has been pending since December 3, 2001, more than five years.